Determining the correlation between line balancing and productivity: a proposal for process improvement

Determinación de la correlación entre el balanceo de línea y la productividad, una propuesta para la mejora de los procesos

Determinando a correlação entre balanceamento de linha e produtividade: uma proposta de melhoria de processos

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Summary. - Line balancing (LB) is a key tool in lean manufacturing that optimizes task allocation, reduces downtime, and increases operational efficiency. This study was conducted in a manufacturing company in the industrial sector, evaluating four of its 19 assembly lines (21%) that presented low productivity, high levels of waste, and late deliveries. This study shows the impact of line balancing on process performance and the savings associated with its implementation. Additionally, two objectives are set: first, to identify external factors, such as employee absenteeism, that negatively affect production and quantify their effect on operational performance. Second, manufacturing tools that help mitigate these impacts must be explored, and solution strategies oriented towards continuous improvement must be developed. This study used a quantitative approach to analyze the relationship between the percentage of added value activities and productivity (pieces per man-hour), demonstrating that the correct application of LB can significantly improve system performance. The results offer practical and sustainable solutions for addressing operational variability and increasing production efficiency.

Keywords: *Line balancing; added value activities; absenteeism; productivity; lean manufacturing.*

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Resumen. - *El balanceo de líneas (LB) es una herramienta de manufactura esbelta que optimiza la asignación de tareas, reduce el tiempo improductivo y aumenta la eficiencia operativa. Este estudio se desarrolla en una empresa manufacturera del sector industrial, evaluando 4 de sus 19 líneas de ensamble (21%) que presentan baja productividad, altos niveles de desperdicio y entregas tardías. Esta investigación muestra el impacto de los balanceos de línea en el desempeño de los procesos, así como los ahorros asociados a su implementación. Además, se plantean dos objetivos: el primero se identifica los factores externos como el ausentismo laboral que afectan negativamente la producción, y se cuantifica su efecto sobre el desempeño operativo; y el segundo, explorar herramientas de manufactura que ayuden a mitigar estos impactos, desarrollando estrategias de solución orientadas a la mejora continua. El estudio utiliza un enfoque cuantitativo, analizando la relación entre el porcentaje de actividades que agregan valor y productividad (piezas por hora-hombre), demostrando que una correcta aplicación del LB mejora el rendimiento del sistema productivo. Los resultados del estudio ofrecen soluciones prácticas y sostenibles para enfrentar variabilidades operativas y elevar la eficiencia productiva.*

Palabras clave: *Balanceo de línea; actividades que agregan valor; ausentismo; productividad; manufactura esbelta.*

***Resumo*. -** *O balanceamento de linha (LB) é uma ferramenta de manufatura enxuta que otimiza a alocação de tarefas, reduz o tempo de inatividade e aumenta a eficiência operacional. Este estudo foi conduzido em uma empresa de manufatura do setor industrial, avaliando quatro de suas 19 linhas de montagem (21%) que apresentam baixa produtividade, altos níveis de desperdício e atrasos nas entregas. Esta pesquisa demonstra o impacto do balanceamento de linha no desempenho do processo, bem como a economia associada à sua implementação. Dois objetivos também são abordados: primeiro, identificar fatores externos, como o absenteísmo de funcionários, que afetam negativamente a produção e quantificar seu efeito no desempenho operacional; segundo, explorar ferramentas de manufatura que ajudem a mitigar esses impactos, desenvolvendo estratégias de solução voltadas à melhoria contínua. O estudo utiliza uma abordagem quantitativa, analisando a relação entre o percentual de atividades que agregam valor e a produtividade (peças por homem-hora), demonstrando que a implementação adequada do LB melhora o desempenho do sistema de produção. Os resultados do estudo oferecem soluções práticas e sustentáveis para lidar com a variabilidade operacional e aumentar a eficiência da produção.*

Palavras-chave: *Balanceamento de linha; atividades que agregam valor; absenteísmo; produtividade; manufatura enxuta.*

1. Introduction. - Production line balancing (LB) allows process optimization and is a critical element in operations management. It minimizes downtime and ensures continuous operation by allocating tasks across different workstations. This constant flow improves productivity indicators on production lines, allowing for the efficient use of available resources [1], [2].

Previous studies suggest that a more balanced workload is associated with improved working conditions, which may lead to lower fatigue, fewer errors, and lower absenteeism in the workplace. Thus, LB aligns with the principles of lean manufacturing, as it promotes waste elimination, continuous improvement, and customer focus [3][4], [5].

To perform proper LB, activities must be classified according to the value they add to the product, distinguishing between added-value (AV) activities, auxiliary work (AW), and non-added-value (NAV) activities. AV activities are those that transform the product and for which the customer is willing to pay, such as assembly, welding, and packaging, among others. However, NVA activities, such as auxiliary activities, are necessary to keep the process running. Finally, pure waste activities are identified, which can be eliminated without affecting the value of the product, such as idle time (waiting), excessive transportation, and unnecessary movements [6].

The identification and quantification of these activities allow for the prioritization of improvement actions. For example, reducing the percentage of non-added value activities has been associated with improvements in productivity, often without the need for significant infrastructure investment [7][8]. Implementing LB techniques in manufacturing industries increases productivity and improves the efficiency of production processes by 15% [8], [9], which indicates the importance of designing and implementing effective balancing strategies to maximize operational performance and reduce inefficiencies.

Simultaneously, recent research indicates that absenteeism affects productivity levels in manufacturing environments. A negative correlation has been identified between absenteeism rates and performance, suggesting that high absenteeism disrupts the standard workflow and reduces overall productivity [9][10]. This situation becomes critical when workers replace absent staff without adequate training, which affects the quantity and quality of production.
In manufacturing systems, absenteeism has been identified as a factor that disrupts production lines, particularly when personnel with varying levels of experience are reassigned to cover absences in the workforce. Several studies have reported a negative relationship between absenteeism and productivity levels, suggesting that variations in employee attendance often coincide with changes in operational performance[11][12][13]. This link underscores the need to establish effective strategies to manage work absenteeism in conjunction with line balancing, as adjustments to the line are required to accommodate workers.

For example, when a worker is absent, the impact is most evident in AV activities, leading to production delays and reduced operational efficiency. To mitigate this effect, it is recommended that cross-training programs be implemented to allow other workers to take on critical tasks in the event of illness-related absences. In this sense, the LB, by providing a breakdown of AV and NVA activities, is a valuable tool for identifying opportunities for improvement and optimizing production in the face of unforeseen circumstances [14].

Various studies have examined the relationship between absenteeism and productivity and found a negative direct relationship. It has also been studied in administrative [15], mental health [16], and socioeconomic settings [17] and in various qualitative studies. However, few case studies have quantitatively addressed this issue in the manufacturing industry, particularly in maquiladoras.

In this context, a maquiladora in the industrial sector with 19 assembly lines across two plants is experiencing low productivity. A sample was taken from four of these lines, representing 21% of the total assembly line. Analysis of the information indicates that the current situation has led to delivery delays on one of the lines, with an absenteeism rate of 75%. In addition, the annual costs associated with idle time and waste on the other lines are estimated at a total of $57,582.4 USD per year, plus $12,153.91 USD for late deliveries due to the same problem.

To solve this problem, this study proposes implementing a lean manufacturing tool, LB, to determine the relationship between the percentage of activities that add value to the process and the performance and productivity metrics. In this study, productivity was defined as the ratio of parts produced by an operator per hour of work [18]. It is measured by recording the total number of parts manufactured and dividing it by the hours worked by the number of operators, thus obtaining the indicator of parts per man-hour. This study also seeks to reduce delivery delays and the costs associated with idle time and waste.

This study will enable the development of strategies to manage work absenteeism by quantitatively analyzing its impact on productivity metrics and identifying its effects on operational performance. The first step is to numerically assess the magnitude of absenteeism's effect, then apply tools such as line balancing to demonstrate its positive impact on productivity. This study aims to examine and understand the variables that negatively affect productivity metrics from a quantitative perspective and to counteract their effects by implementing solutions that improve overall process performance, are easy to implement, and are familiar to the engineers in charge of the production lines.

Section 2 includes the methodology for this research, following the introduction. Section three discusses the results, section four reports the conclusions, and section five presents the limitations and future research Directions

2. Methods. - The methodology used in this research is based on the DMAIC cycle (Define, Measure, Analyze, Improve, and Control), complemented by lean manufacturing tools, to improve processes affected by external variations. This approach is based on five phases, as shown in Figure 1, which indicates the techniques used in each stage and the integration of the lean manufacturing tools.

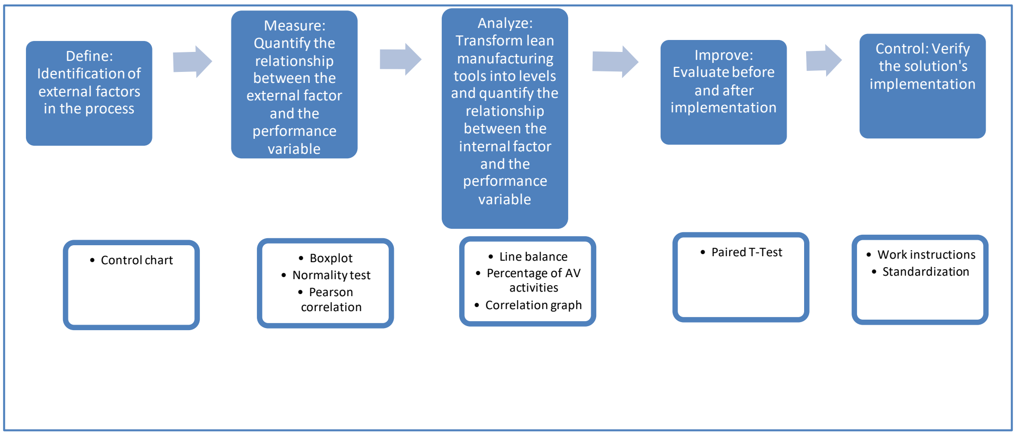

Figure I. - Proposed methodology.

2.1 Define phase: Identification of absenteeism in the process. This phase aimed to gather the necessary information to identify the impact of absenteeism on process performance, measured through productivity. To this end, operational data was collected from the most recent reports, including the number of pieces produced, the number of operators present on the work team, the number of absences, and the time worked. This information enabled the calculation and analysis of productivity using an $\bar{X}$-R control chart in Minitab 17®. The use of the $\bar{X}$-R chart is justified by its ability to monitor process variability and distinguish it from variability associated with specific causes. A rational subgrouping strategy was applied, in which each subgroup consisted of five consecutive data points produced under homogeneous operating conditions, such as the same shift and manual assembly process characteristics. In this way, the variation within each subgroup primarily reflects the inherent variability of the process (common causes), while the variation between subgroups allows the identification of changes in process conditions, particularly those associated with fluctuations in labor availability due to absenteeism. Furthermore, sampling was conducted at intervals aligned with the production ID cycles to ensure stable sampling logic. Under these conditions, the $\bar{X}$–R chart constitutes a valid method for identifying significant variations due to special causes, considering absenteeism as a central explanatory variable of productivity performance.

Equation 1 measures the percentage of absenteeism, and Equation 2 calculates the average.

$$\text{Absenteeism percentage} = \frac{\#\, absent\ operators}{Total\ number\ of\ operators\ to\ perform\ the\ assembly} * 100 \qquad (1)$$

$$Average\ percentage = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad (2)$$

Where:

X_i = each of the percentage values
n = total number of values

2.2 Measure Phase: Quantification of the relationship between absenteeism and productivity. Once the variations attributable to special causes of absenteeism in the process are identified, the collected information is analyzed using a box plot to detect outliers. If such values are identified, the data are cleaned to ensure the sample is representative of the process's normal behavior.

Normality tests were then applied to verify whether the data followed this distribution, a necessary condition for calculating the correlation coefficient between two variables. Additionally, each productivity point represented in the Xbar-R control chart was associated with its corresponding absenteeism value. It is used to analyze the relationships between external variables and process variables in the context of productivity.

The assumptions of linearity and independence of the data were reviewed using residual analysis. Subsequently, linear regression analysis and Pearson's correlation coefficient were calculated to quantify the strength and direction of the relationship between absenteeism and productivity. All statistical calculations, including the estimation of the regression equation, were performed using the Minitab statistical software.

Data quality was assessed by reviewing system data records and comparing them with paper records to identify typos. If this typo matched the outlier, the data were removed from the sample so that the data's correct behavior could be represented.

2.3 Analyze: Transformation of the line balancing tool into levels and quantification of the relationship between line balancing and productivity. -Within the analysis phase, to quantify a value for the line balancing tool that allows a relationship with productivity to be established, the analysis phase is divided into three stages. The first stage applies the line-balancing methodology. In the second stage, activities are quantified by their contribution to balancing; that is, all activities that add value are identified and measured to determine the percentage they represent in the total process. Finally, in the third stage, the AV activities are quantified following the steps from the previous stage, with the difference that this stage extends them across multiple production lines within the manufacturing company. In addition, the productivity corresponding to each line balancing was quantified to identify the relationship between the percentage of AV activities and productivity.

In the first stage, the methodology corresponding to the selected tool, namely line balancing, is applied. Figure II presents the specific methodology used to apply the line balancing tool, corresponding to step one of the analysis, which consists of three steps: In step one, the takt time is calculated, which starts from knowing the actual demand and distributing this demand in equal amounts over a given period of time, that is, knowing the demand from week one to week four to calculate the weekly average of parts that must be built to meet the customer demand. Next, the time available for assembling the parts was estimated by subtracting the mealtimes per shift from the total available time. This data is then used to calculate the takt time, as shown in Equation 3:

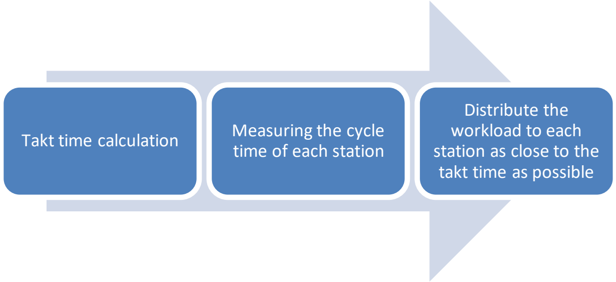

Figure II.- Methodology for the implementation of the line balancing tool

$$\text{Takt time} = \frac{Worktime}{Demand} = \frac{Days\ worked\ per\ week * First\ plus\ second\ shift\ available\ time \frac{hours}{days} * 3600 \frac{seconds}{hours}}{Average\ weekly\ demand\ units} \quad (3)$$

In the second step, the cycle time of each station was measured in seconds. In the third step, the workload is distributed to each station as close as possible to the takt time. These steps completed the first stage of the analysis phase, and stages two and three were then carried out.

In the second stage, all activities necessary to execute the production process are classified in detail and grouped into three main categories: added-value activities (AV), auxiliary activities (AW), and non-added-value activities (NAV).

In addition to these three categories, an analysis of the waste generated between the stations was incorporated. This type of waste can cause idle time due to cycle-time imbalances between stations or to overproduction when one station continues to operate. Simultaneously, the next station has a longer cycle time, which leads to product accumulation in the process.
To determine the percentage of added value activities (AV) within line balancing or within a workstation, we began by classifying all tasks into four categories: added value activities (AV), auxiliary work (AW), non-added value activities (NAV), and idle time (waste between stations).

We began by calculating the total time per workstation by summing the times for the first three categories (AV, AW, and NAV). Next, we identified the station with the longest total time, which represents the process bottleneck. The difference between this maximum time and the times of the other stations is considered waste by balance and is classified as a fourth category: idle time.

In this way, the four components per station are calculated: AV, AW, NAV, and idle time, the sum of which represents 100% of the components within the balancing. The percentage of added-value activities is calculated by dividing the sum of AV time (either for a specific station or for the entire balancing) by the total time for the four categories of activities. This quotient was multiplied by 100 to obtain its value as a percentage, as shown in Equation 4:

$$\%AV = \left(\frac{\sum AV}{\sum(AV+AW+NAV+Idle\ time)}\right) * 100 \quad (4)$$

In the third stage, the relationship between the percentage of added-value activities and the productivity performance of the different production lines is graphically presented. In addition, a linear regression analysis was performed to model the relationship between these variables, including the estimation of the regression equation, the slope parameter, and its corresponding confidence intervals. The normality of the residuals was assessed to verify the model's assumptions. All statistical analyses were performed using Minitab v.19.

2.4 Improve: Alternative solutions for line balancing and evaluation of levels (initial and final status). The proposed alternative solution involves implementing the LB tool to optimize production process performance by more efficiently allocating tasks. The improvement considers a quantitative evaluation of the initial state and the state after implementation based on the analysis of the percentages of activities that add value within line balancing.

To validate the solution's effectiveness, a statistical hypothesis test was conducted to determine whether the achieved levels represented a significant improvement over the process's initial state. This validation provides an objective basis for confirming that the application of these tools not only generates operational benefits but also that these benefits are statistically relevant and sustainable over time.

2.5 Control: Verification of the application of line balancing. – This phase seeks to ensure the sustainability of line balancing as an improvement solution so that it continues to be implemented over time to preserve the benefits obtained during the study. To this end, adjustments are made to the instructions and production system to maintain the desired level; that is, the percentage of added-value activities is preserved in the analyzed processes and consistently applied during the execution of the manufacturing process.

3. Results and Discussion. – This section is divided into sections according to the information on the DMAIC methodology reported earlier.

3.1 Define: Identification of absenteeism in the process of training. – Process behavior is monitored using the Xbar-R control chart, which shows how productivity is influenced by absenteeism. Figure III shows the data collected over the five months of production, with a total of 115 observations grouped into subgroups of five, yielding 23 points on the graph. Point 12 falls below the lower control limit (LCL), indicating an abnormal drop in productivity for this subgroup. This drop indicates the presence of a specific cause of absenteeism, leading to a significant decrease in process performance.

However, points 12, 13, and 22 on the range chart showed signs of being out of control, suggesting unusual variation within those subgroups. Although in samples 13 and 22 the mean remained within the control limits, the variability exceeded the upper control limit (UCL) due to external factors that disrupted the normal process development.

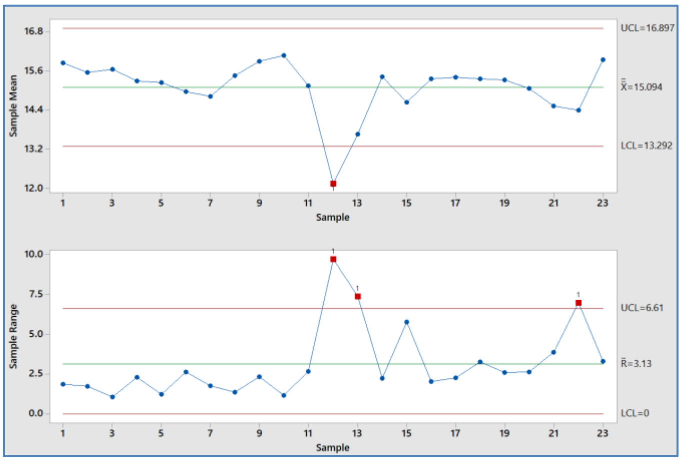

Figure III.- Control chart of productivity

3.2 Measure: Quantification of the relationship between absenteeism and productivity. – Outliers in the process were excluded from the sample to measure the relationship between absenteeism and productivity. Figure IV shows the box plot, in which it can be seen that the data are concentrated in the first quartile (Q1) of 14.95 and the third quartile (Q3) of 15.55, with minimum and maximum values within the range of 14.39 to 16.07, thus showing that sample number 12 with a value of 12.15 is outside the process range. Therefore, it was removed from the analysis, leaving 22 points.

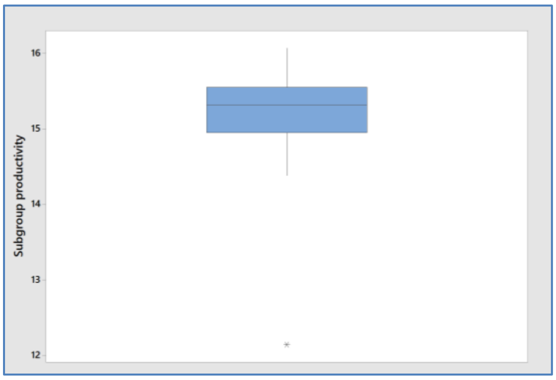

Figure IV- Boxplot for productivity

Once the outlier corresponding to observation 12 was identified and removed, the Anderson-Darling normality test was applied to assess the data's statistical behavior. As shown in Figure V, the p-value obtained was 0.847, indicating insufficient evidence to reject the null hypothesis of normality; therefore, the data exhibited an approximately normal distribution. Furthermore, Figure VI shows a plot of residuals versus fitted values, which displays random dispersion around the zero-reference line without any systematic patterns or evident curvilinear trends, suggesting that the model's linearity assumption is adequately met. Additionally, the residuals' variability remained approximately constant across the range of fitted values, indicating homoscedasticity and supporting the suitability of the linear regression model. Finally, Figure VII presents the evaluation of the independence of observations by analyzing the residuals based on the order of data collection, as well as the Durbin-Watson statistic, which had a value of 1.89. This result did not indicate autocorrelation, confirming the assumption of independence.

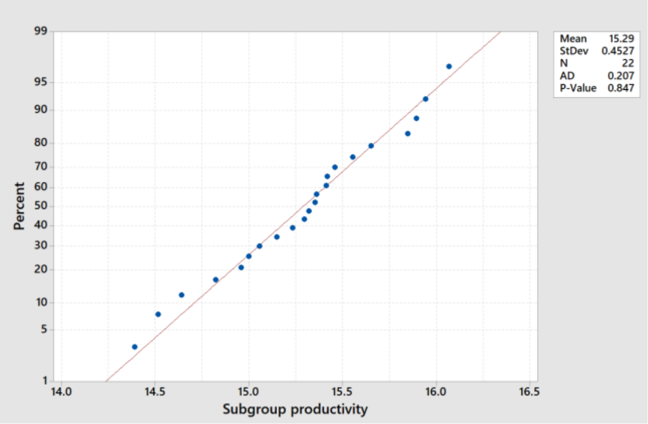

Figure V.- Normality test for productivity

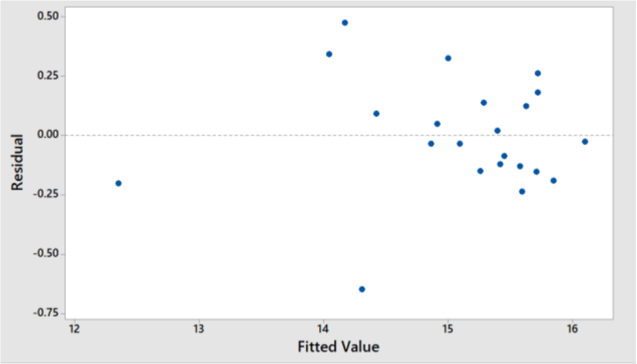

Figure VI.- Residuals versus Fits

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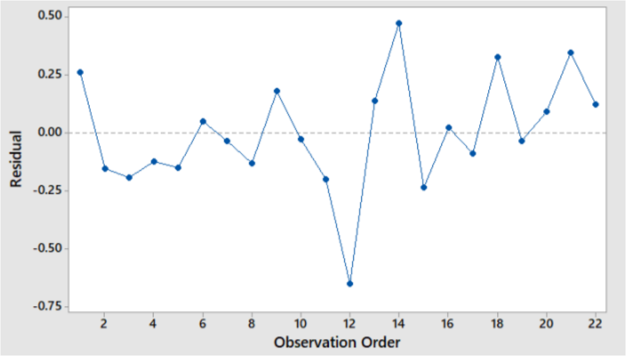

Figure VII.- Residuals versus Order

After verifying that the assumptions of the absence of outliers, normality, linearity, and independence of the data were met, a linear regression analysis was performed to evaluate the relationship between absenteeism and productivity. The results, presented in Figure VIII, show a statistically significant negative relationship, described by the model Productivity = 16.0958 − 0.1900 · Average Percentage. Under these conditions, a Pearson correlation coefficient of −0.960 was obtained, indicating a strong inverse linear association between the two variables.

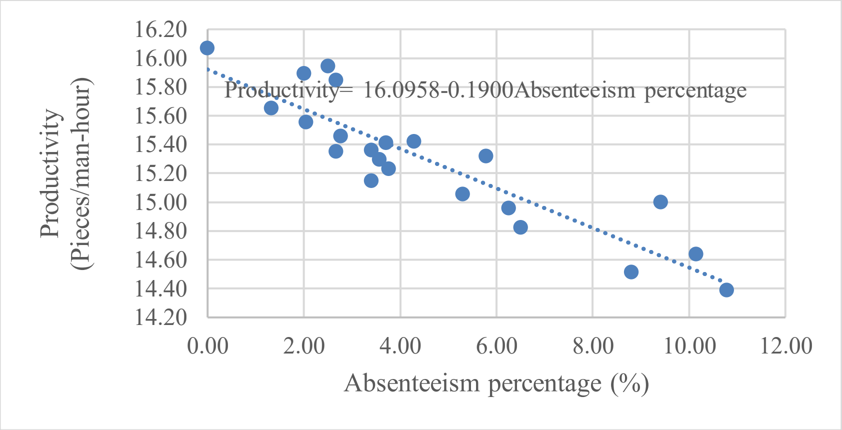

Figure VIII- Relationship between productivity and absenteeism

3.3 Analyze: Transformation of the line balancing tool into levels and quantification of the relationship between line balancing and productivity. In this phase, we explored whether the line balancing tool had the opposite effect on absenteeism. In line balancing, we analyze its contribution to increasing productivity and then identify the simplest operations to assign to inexperienced workers, who cover the work of absent operators.

The results obtained in the first stage, which involve applying the line balancing methodology, consist of determining customer demand to calculate the takt time. Table I shows the projected demand for the next four weeks, with a weekly average of 6,493 units per week. Table II shows the time available during the first shift, and Table III shows the time available during the second shift, for a total of 16.5 h per day.

Week	Forecast	Average
1	5,293	6,493
2	7,593	
3	7,639	
4	5,393	

Table I.- Average weekly demand

Activities	Time (h)	Percentage
Available work time	8.5	91.39
Breakfast	0.3	03.00
Lunch	0.5	05.00
Total	9.3	100

Table II.- First shift available time

Activities	Time (h)	Percentage
Available work time	8.0	90.9
Lunch	0.3	05.68
Dinner	0.5	03.40
Total	8.8	100

Table III.- Time available second shift

Takt time is defined as the time interval expressed in seconds in which a unit must be produced to meet customer demand within the available operating time, that is, the total time available between demands, which in this case corresponds to five working days, with a daily shift of 16.5 hours (considering the first and second shifts) and expressed in seconds when multiplied by 3600 and divided by the 6,493 weekly pieces, yields a value of 45.74 seconds per piece.

The next step in the line-balancing process is to measure the cycle time at each workstation. Table IV presents the average times recorded for each activity within the process, along with their sum, which corresponds to the total cycle time at that station, yielding a cycle time of 55.70 seconds. The information for calculating the times for the other stations is in the supplementary material. The cycle times for each station were S1 = 55.71 seconds, S2 = 46.65 seconds, S3 = 55.1 seconds, and S4 = 41.3 seconds.

Figure IX compares the cycle times of each workstation (S1, S2, S3, and S4) with the previously calculated takt time for the four workstations. This analysis shows that stations one, two, and three (S1, S2, and S3) have cycle times greater than the takt time of 45.74 seconds, indicating that, in their current state, these stations cannot meet the projected demand for the four weeks. Therefore, lean manufacturing tools must be used to balance workloads across stations and ensure production targets are met.

Description	**Chronometry (input in seconds)**										**Results**
Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average (sec)**
STATION 1											
Cutting contacts	5.30	4.51	2.57	6.14	5.18	4.58	2.82	4.50	5.25	7.83	4.87
Post trimming	3.56	4.02	4.31	4.74	4.04	5.80	3.11	3.59	4.37	4.06	4.16
Ring placement	2.80	4.05	3.09	2.74	3.39	2.66	2.61	3.27	2.75	3.06	3.04
Button placement	3.59	2.50	2.59	2.82	2.45	2.44	4.26	2.70	3.60	2.79	2.97
Button placement	5.83	3.80	3.18	3.33	3.06	3.16	3.19	2.97	3.34	2.59	3.45
Button retainer placement	2.25	2.59	4.09	2.60	3.94	2.37	3.36	3.37	3.66	3.42	3.17
Ultrasonic welding	5.80	6.92	5.88	6.55	5.90	6.70	5.98	6.74	6.96	7.77	6.52
Place 2 O-rings	6.95	6.15	6.11	6.62	7.11	6.15	6.65	7.15	7.00	6.75	6.66
Cut retainer	5.30	4.83	3.45	5.20	5.30	6.50	6.10	5.20	5.30	5.50	5.27
Apply hot melt	16.35	16.60	16.32	16.30	15.20	14.50	16.30	14.90	2:90	15.00	15.60
Total sum of the steps											55.70

Table IV.- Cycle time station 1

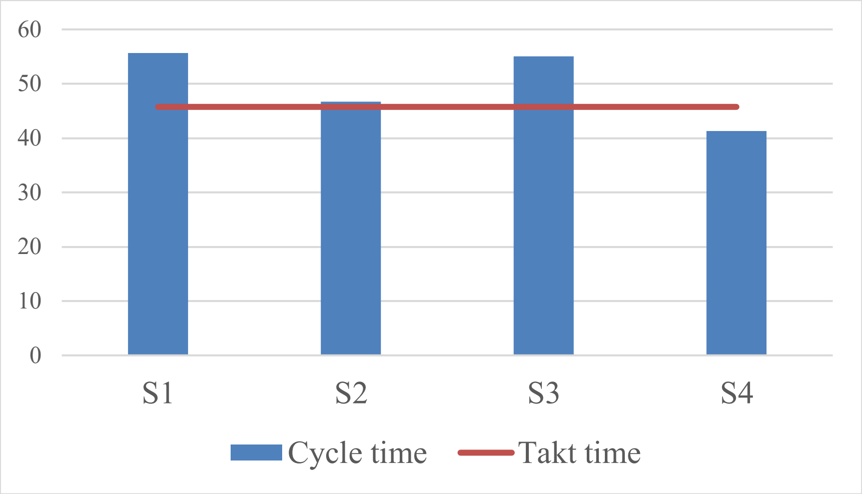

Figure IX- Cycle time vs takt time

Given the need to meet established demand, the line-balancing tool is used to optimize the workflow. In this case, tasks are redistributed by adding a fifth station, S5, to reduce cycle times at stations 1, 2, and 3, which previously exceeded the takt time.

Table V shows the new assignment of activities for station one (if you want to know the assignment for the rest of the stations, refer to the supplementary material). Figure X shows the cycle time graph for station one and the rest of the stations with a comparison of the cycle times per station with respect to the new takt time, in which a cycle time is obtained for S1 40.59 seconds, S2 = 41.81 seconds, S3 = 43.57 seconds, S4 = 43.06 seconds, and S5 = 40.45 seconds. This graph shows greater temporal alignment between the stations and a better approximation of the takt time, reflecting a more balanced workload. As a result, the process is significantly improved, and compliance with customer requirements within the established period is ensured.

Description	**Chronometry (input in seconds)**										**Results**
Activity	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Average (sec)**
STATION 1											
Cutting contacts	6.30	5.51	3.57	7.14	6.18	5.58	3.82	5.50	6.25	8.83	5.87
Post trimming	4.56	5.02	5.31	5.74	5.04	6.80	4.11	4.59	5.37	5.06	5.16
Ring placement	2.80	5.05	4.09	2.74	3.39	3.66	3.61	3.27	3.75	4.06	3.64
Button placement	3.59	2.50	2.59	2.82	2.45	2.44	4.26	2.70	3.60	2.79	2.97
Button placement	6.93	4.80	4.18	3.33	3.06	4.16	4.19	2.97	4.34	3.59	4.16
Button retainer placement	3.25	3.59	5.09	3.60	4.94	3.37	4.36	4.37	4.66	4.42	4.17
Ultrasonic welding	6.80	7.92	6.88	8.55	6.90	7.70	6.98	7.74	7.96	8.77	7.62
Walk to the packing station	5.21	4.21	3.97	4.20	4.10	3.80	4.50	4.60	3.50	3.20	4.13
Bag unit	1.49	4.18	4.75	4.04	3.90	2.30	2.50	3.60	3.90	3.20	3.39
Total sum of the steps											41.10

Table V.- Cycle time station 1

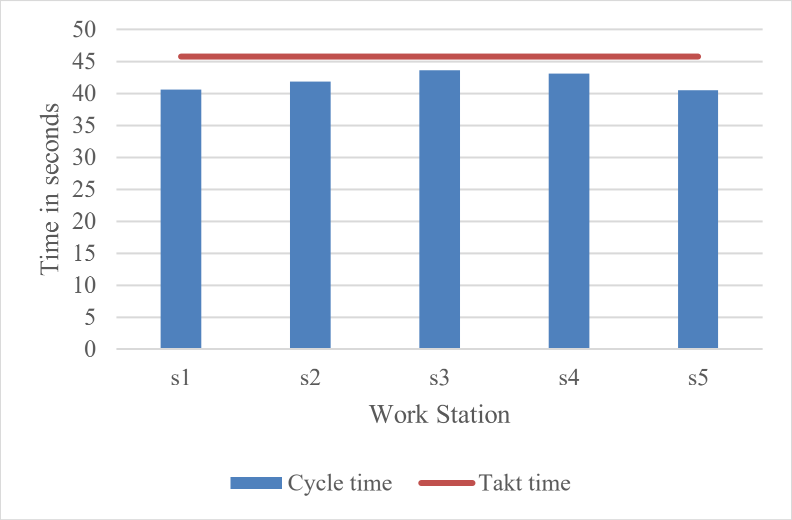

Figure X.- Cycle time vs. takt time after balancing

Thus far, the steps corresponding to stage one of the lean manufacturing methodology for line balancing tools have been applied. Next, we begin stage two, in which we perform a detailed classification of all activities necessary to execute the production process. This classification allows us to analyze the impact of line balancing on productivity based on the percentage of activities that add value within the process.

Table VI shows the classification of each of the activities corresponding to station one (the rest of the stations are found in the supplementary material) according to four categories: Added Value (AV), Auxiliary Work (AW), Non-Added Value (NAV), and idle time (IT). Figure XI complements this information by graphically showing the distribution of these categories and visualizing idle times resulting from cycle-time differences between stations.

The analysis by station using Equation 5, explained in the methodology, reveals the following results, both per station and for the total balance:

- Station one: For the time in seconds of the total activities that make up this station, we have a total AV time of 25.94 s, an AW of 0 s, a NAV of 15.16 s, and idle times of 4.64 s. Adding all the categories gives a total value of 45.74 seconds. Applying Equation 5 of the methodology to determine the ratio of AV activities within Station One gives a participation percentage of 56.7%.
- Station two: The time for AV activities was 38.77 seconds, AW was 3.84 seconds, NAV was 0 seconds, and the idle time was 3.14 seconds, for a total of 45.74 seconds. This resulted in a participation ratio of 84.71% for AV activities.
- Station three: The AV, AW, NAV, and idle times were 34.08, 7.11, 3.72, and 0.82 s, respectively, for a total activity time of 45.74 s. This resulted in a participation ratio of 74.5% for AV activities.
- Station four: AV activities lasted 40.35 s, AW activities lasted 0.39 s, NAV activities lasted 4.99 s, and idle time lasted 0 s, for a total of 45.74 s of activity. This resulted in a participation ratio of 88.2% for AV activities.
- Station five: AV activities lasted 0 s, AW activities lasted 9.21 s, NAV activities lasted 31.19 s, and idle time lasted 5.34 s, giving a total activity time of 45.74 s. This resulted in a participation ratio of 0% for AV activities.

Overall, the balancing analysis showed a time of 139.14 s for AV activities, 20.54 s for AW activities, 55.06 s for NAV activities, and 13.96 s for idle time, giving a total of 228.71 s of activity. This resulted in a participation ratio of 60.83% for AV activities, which allowed us to quantify the improvement in work distribution based on system productivity.

Description of Study		**Chronometry (input in seconds)**										**Results**
Activity	**Operation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Ave (sec)**
STATION 1												
Cutting contacts	NAV	6.30	5.51	3.57	7.14	6.18	5.58	3.82	5.50	6.25	8.83	5.87
Post trimming	NAV	4.56	5.02	5.31	5.74	5.04	6.80	4.11	4.59	5.37	5.06	5.16
Ring placement	AV	2.80	5.05	4.09	2.74	3.39	3.66	3.61	3.27	3.75	4.06	3.64
Button placement	AV	3.59	2.50	2.59	2.82	2.45	2.44	4.26	2.70	3.60	2.79	2.97
Button placement	AV	6.93	4.80	4.18	3.33	3.06	4.16	4.19	2.97	4.34	3.59	4.16
Button retainer placement	AV	3.25	3.59	5.09	3.60	4.94	3.37	4.36	4.37	4.66	4.42	4.17
Ultrasonic welding	AV	6.80	7.92	6.88	8.55	6.90	7.70	6.98	7.74	7.96	8.77	7.62
Walk to the packing station	NAV	5.21	4.21	3.97	4.20	4.10	3.80	4.50	4.60	3.50	3.20	4.13
Bag unit	AV	1.49	4.18	4.75	4.04	3.90	2.30	2.50	3.60	3.90	3.20	3.39
Total sum of the steps												41.10

Table VI. - Classification of activities station 1

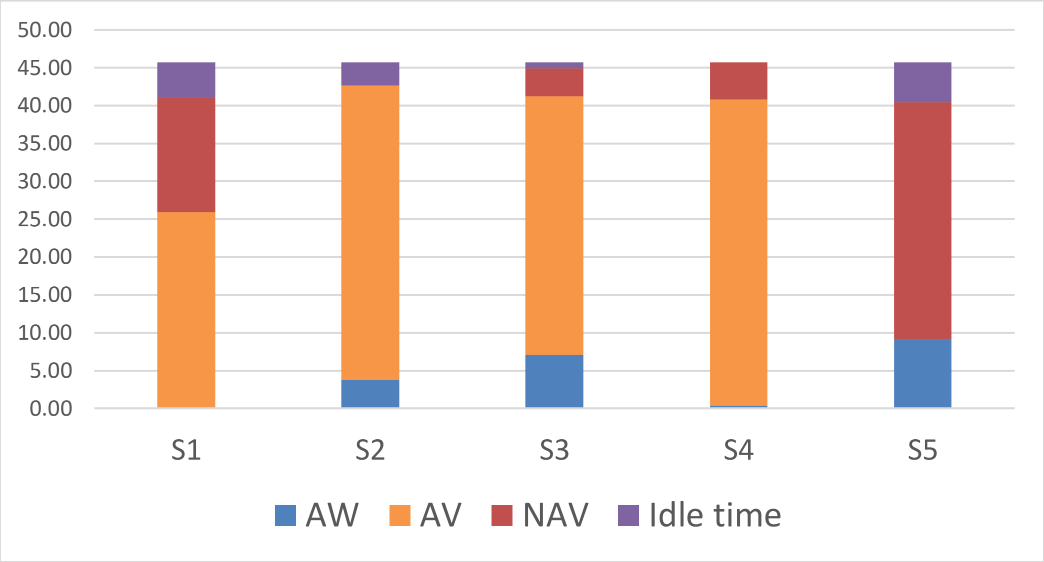

Figure XI.- Cycle time with activity classification

As part of the third stage of the analysis, which establishes the relationship between the line balancing tool and productivity, the participation of AV activities within the different balances for the four assembly lines of the manufacturing company was calculated. Table VII presents the results, showing both the percentage of added-value activities and the productivity for each balance (for information on the balances, classifications, and productivity, see the Supplementary Material).

Figure XII shows a positive, statistically significant relationship between the percentage of added-value activities and productivity, with a correlation coefficient of 0.9428, indicating a strong linear association between the two variables. To further quantify this relationship, a linear regression analysis was conducted, yielding the model: *Productivity = 1.57 + 0.2310·Percentage of added value (%)*. The estimated slope ($\beta_1 = 0.2310$) reflects the magnitude of the linear effect of added value activities on productivity. The 95% confidence interval for the slope [0.1796, 0.2823] did not include zero, confirming the effect's statistical significance ($p < 0.001$). Residual analysis revealed a normal distribution.

Production line and balancing number	Percentage of added value (%)	Productivity (Pieces/man-hour)
Line one balancing 1	53.42	13.03
Line one balancing 2	76.44	19.15
Line one balancing 3	78.5	19.93
Line two balancing 1	40.16	11.3
Line two balancing 2	44.29	13.2
Line two balancing 3	48	12.91
Line two balancing 4	49.72	13.99
Line three balancing 1	41.93	9.92
Line three balancing 2	48.92	11.58
Line three balancing 3	58.73	13.89
Line four balancing 1	48.46	12.66
Line four balancing 2	58.01	14.86
Line four balancing 3	60.83	15.7
Line four balancing 4	56.17	16.15

Table VII- Percentage of added value activities and their corresponding productivity

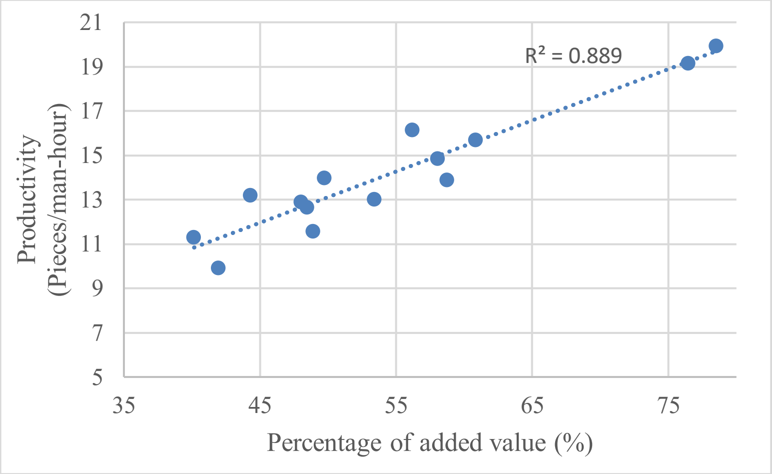

Figure XII.-Relationship between added value activities and productivity

3.4 Improvement: Alternative solutions for line balancing and evaluation of levels (initial and final status). – The time studies corresponding to the four assembly lines were analyzed and compared with the results obtained at the different line balancing levels. This analysis shows an increase in the proportion of added-value activities relative to the total activities included in the studies and the balancing process.

Table VIII shows the productivity levels achieved on each line when comparing level one balancing, which corresponds to the initial state of balancing, with level two balancing, which corresponds to the final state (if you want to see all the data in the table, check the supplementary material), leaving the alternative hypothesisH_1: Productivity is lower in the initial state than after the application of balancing in the final state. Table IX presents the results of the Paired T-test, which indicate a significant difference in productivity when the participation in added-value activities within line balancing is increased.

Production Line	Balancing before	Balancing after
One	13.17	20.25
One	11.50	17.63
One	13.33	20.50
One	13.50	20.00
One	13.17	20.00
…	…	…
Four	12.71	16.00
Four	11.14	14.25
Four	13.00	16.50
Four	13.14	16.75
Four	12.86	16.25

Table VIII.- Productivity balancing before and after

Sample	N	Mean	St Dev	SE Mean
Balancing before	28	11.687	1.368	0.259
Balancing after	28	15.924	2.522	0.477
Difference	28	-4.237	1.541	0.291

Null hypothesis	H_0:µbefore−µafter =0
Alternative hypothesis	H1:µbefore−µafter <0
P-Value	$P<0.001$

Table IX- 2 Paried T-Test and hypothesis test balancing before and after

3.5 Control: Verification of line balancing implementation. - The operating instructions for lines one, two, three, and four were updated to detail the steps to be followed at each workstation. These instructions reflect the distribution of activities defined by the previously analyzed line balancing, ensuring their correct execution in the production process.

The control system was also updated to reflect the standard times established by the model on each line, in accordance with the values determined in line balancing. As part of the operational monitoring, visual control boards were installed, which were updated in real time by the group leaders. This tool allows for continuous monitoring of process performance and, with the support of various support departments, facilitates the timely implementation of necessary adjustments to maintain the expected productivity levels.

4. Discussion of the results and conclusions. - In the initial scenario of the manufacturing company in the industrial sector, consisting of 19 assembly lines distributed across two of its plants, a problem of low productivity and delivery delays on one of its lines, with an incidence of 75%, was reported. From the sample taken from the four lines, the annual costs associated with idle time and waste were estimated at $57,582.4. This study has two objectives: first, to identify the impact of absenteeism on productivity and quantify its effect on this problem; second, to explore the line balancing tool to understand the behavior that can counteract the effect of absenteeism on productivity, thereby creating problem-solving strategies through the use of this tool.

The impact of work absenteeism on manufacturing production processes has not been sufficiently studied, which limits a comprehensive understanding of its implications for operational efficiency. Although there is research [19] that addresses this phenomenon, its focus is on administrative environments without delving into the specific problems that absenteeism generates in production environments, such as delivery delays or costs associated with the interruption of continuous flow.

To address the first objective, tools commonly used in industrial process monitoring were employed, such as those applied in the molding [20], metal processing [21], and glass [22]sectors, where critical dimensional variables are controlled to ensure product quality. However, in this study, the graphical control tool was used from a different perspective, as it was not applied to product characteristics but rather to a key indicator of process performance, which provides a comprehensive view of the system's behavior.

The analysis using control charts identified two out-of-control points in the mean chart and three in the range chart, all of which were attributed to employee absenteeism. These points represent variations attributable to special causes that are outside the process. Further analysis of the outliers using a box plot revealed that the value for sample 12 was an outlier. By excluding this point and recalculating the impact of absenteeism on productivity, the Pearson correlation coefficient obtained was -0.960, confirming a negative relationship between these two variables. In addition, the estimated slope of the regression equation $Productivity = 16.0958 - 0.1900$ ($\beta_1 = -0.1900$) indicates a negative linear effect of absenteeism on productivity, with a magnitude of −0.1900. Once the impact of the external factor on system performance was determined, the second objective focused on developing improvement strategies using the line balancing tool, which made it possible to address the problem of delays on one of the lines, where 75% on time delivery was not being achieved. As a result, a substantial improvement in workflow efficiency was achieved, generating estimated annual savings of $12,153.91 USD, in addition to a significant reduction in idle time and overproduction between workstations.

The line balancing tool has been widely used to optimize production processes and achieve significant increases in operational efficiency. For example, in the garment industry, its implementation increased productivity from 54.22% to 66% [23] the manufacture of automotive parts, an improvement of 7.7% was achieved [24]; and in the electronics industry, it contributed to the elimination of bottlenecks [25].

Despite these results, few studies have quantitatively analyzed the impact of line balancing on productivity using correlation-based metrics to provide an objective parameter that would facilitate the design of more precise interventions to address issues inherent in the dynamic environment faced by manufacturing organizations.

To evaluate the impact of these tools on process performance, a detailed classification of all activities involved in line balancing was performed, including those considered waste, specifically those associated with the idle time. This analysis enabled calculating the percentage of activities that added value for each evaluated line and relating this indicator to the observed productivity levels. The correlation results show that the LB tool maintains a positive relationship with productivity, with a coefficient of 0.9428. Finally, the increase in these activities within the assembly lines resulted in additional savings of $57,582.4 USD per year, attributable to the elimination of unproductive time and the reduction of waste.

5. Limitations and Future Research Directions. - It is important to note that this study was developed using a sample corresponding to the assembly line of an industrial manufacturing company. However, the methodology and analysis approach can be replicated in other production processes, such as injection molding, metal treatment, and painting. This suggests that the findings have broader applicability in industrial environments, provided that the specific characteristics of each process are considered.

One limitation of this study is that lean manufacturing tools were used to evaluate their impact on performance indicators, with a focus mainly on productivity. The analysis focused on determining the direction (positive or negative) and magnitude of this impact as a basis for proposing improvement strategies that integrate both external and internal factors of the production system. However, this approach did not consider interactions with other tools or between the internal factor LB and the external factor absenteeism.

For future research, it is recommended to broaden the scope of the study by incorporating additional lean manufacturing tools or by developing an analysis that considers both external and internal factors to design robust processes. In this way, even in the face of uncontrollable external factors such as absenteeism, their impact on productivity can be reduced, promoting the stability and efficiency of the operating system.

Availability of information/Supplementary material

Hermosillo, Fabiola (2025), "Line balancing and productivity," Mendeley Data, V1, doi: 10.17632/5d7vn57xnn.1

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Author contribution:
1. Conception and design of the study
2. Data acquisition
3. Data analysis
4. Discussion of the results
5. Writing of the manuscript
6. Approval of the last version of the manuscript

FHV has contributed to: 1, 2, 3, 4, 5 and 6.
JLGA has contributed to: 1, 2, 3, 4, 5 and 6.
OCG has contributed to: 1, 2, 3, 4, 5 and 6.

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